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Magnetic field distribution inside the aperture of a Steerer magnet prototype

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Abstract

- The HESR (High Energy Storage Ring), important part of the FAIR (Facility for Antiproton and Ion Research), contains, among other magnets, 53 corrector magnets, for vertical and horizontal deflection of the beam.

- A prototype of a 2 mrad vertical steerer magnet was designed by ICPE-CA Romania in close cooperation with Forschungszentrum Jülich Germany
- The prototype was manufactured and tested by ICPE-CA.
- Was made magnetic field measurements using a 3D Hall probe.
- Measured data and their analysis are presented. System used for positioning of the Hall probe and data acquisition are also described.

Magnet design and construction

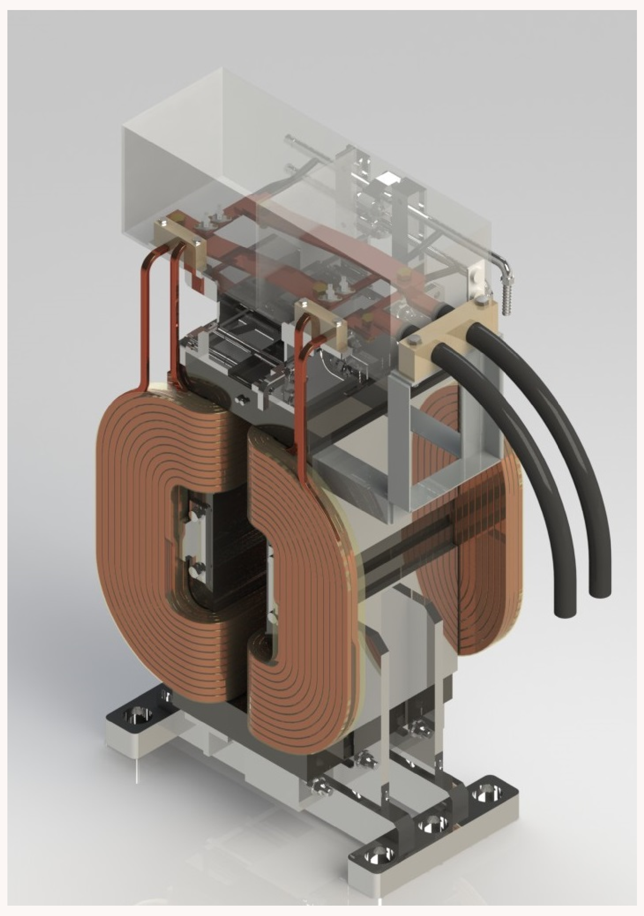

Fig. 1: The Steerer Magnet: 3D model

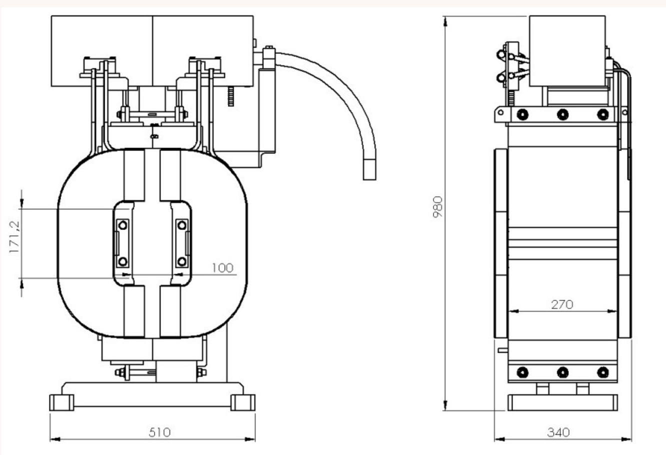

Fig. 2: The Steerer Magnet: 2D model

Fig. 3: The Steerer Magnet: Prototype

Power Supply - Parameters

- Input :50Hz, 400V, 3 phases;
- Output voltage : ±45V
- Output current : $0 \div 350$A
- Current slew rate :20A/s
- Accuracy : 0.0001
- Environment : $18 \div 28^0$C
- Cooling demineralised water with:
  - → $< 10\mu$S/m conductivity;
  - → 25 ± 1^0C flow temperature;
  - → 6 bar advanced pressure;
  - → 4 bar permitted difference.

Input Parameters

Parameters

- Max deflection angle: 2mrad at p_{max};
- Aperture (diameter): 100mm;
- Magnetic length: 300mm;
- Iron yoke length: 270mm;
- Iron yoke width: 580mm;
- Iron yoke height: 450mm;
- Mass of iron (magnetic circuit): ≈ 160kg;
- Number of coils: 2;
- Windings / coil: 44;
- Layers / coil: 4;
- Windings / layer: 11mm;
- Conductor dimensions: 10.6×7mm^2;
- Cooling bore: 4mm;
- Cooper crossection: 66.77mm^2;
- Length of conductor /coil: ≈ 72m;
- Cooper mass /coil: ≈ 39kg.
- Max deflection angle : 2mrad at p_{max};
- Current: 304.1A;
- Current density: 5A/mm^2;
- Voltage (DC): 12.84V;
- Resistance: 42.2mΩ ;
- Inductivity: 0.28mH ;
- Power (DC): 3.9kW ;
- Water flowrate: ≈ 1.81l/min ;
- Pressure drop Δp: 5.21bar.

First magnetization curve:

B[T]	0.12	1.45	1.70	1.80	2.0
H[A/m]	50	700	4000	8000	25000

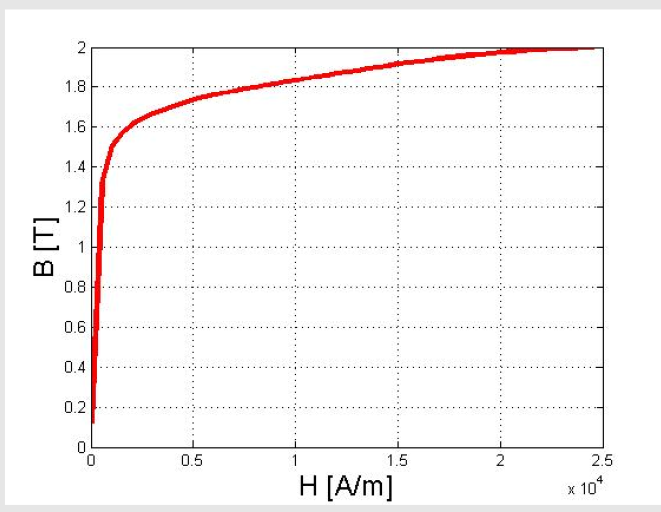

Fig. 4: First magnetization curve (BH)

Formulas

$$R = \frac{l_\delta}{2\sin\frac{\varphi}{2}} = 150\text{m}; \quad (1)$$

$$B_C \simeq \frac{p_{max}}{0.3R} = 0.333\text{T}; \quad (2)$$

$$B \cdot R = 50\text{Tm} \quad (3)$$

$$s = R\left[1 - \cos\left(\frac{\varphi}{2}\right)\right] = 75\text{mm} << A = 100\text{mm} \quad (4)$$

Measurement System

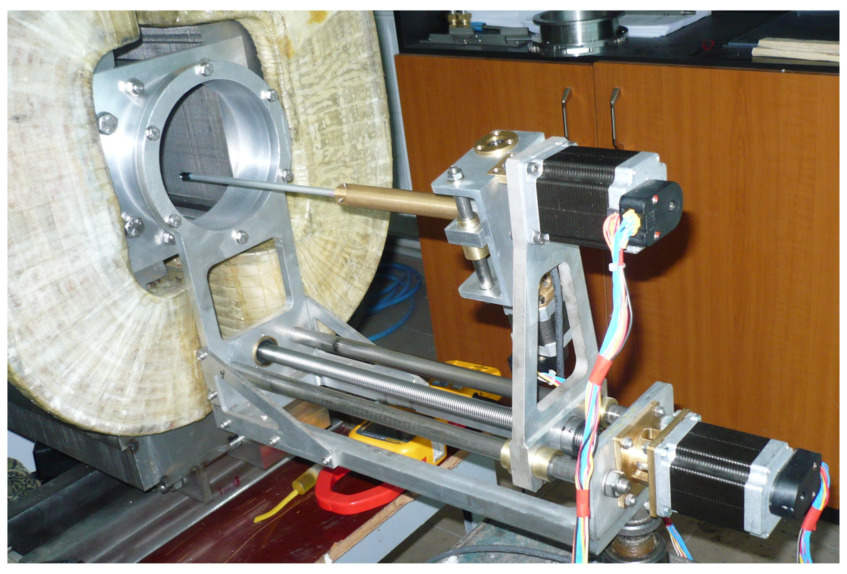

Fig. 5: Measurement system device for positioning the Hall probe

- a gaussmeter with a 3D Hall probe;
- a special device for positioning the Hall probe inside the aperture;
- stepper motors for moving the Hall probe in Cartesian coordinates.
- a digital multimeter;
- an interface between the gaussmeter and the positioning device control system;
- a PC for controls input, data acquisition and data processing;
- a digital multimeter with a thermocouple probe, to monitor the temperature of the coils.

Experimental data

Experimental data of B[T] for $z = 0$mm

θ^0	$R[mm]$	$I_1 = 50$A	$I_2 = 100$A	$I_3 = 150$A	$I_4 = 200$A	$I_5 = 250$A	$I_6 = 304$A
0	37.5	0.05519	0.11077	0.16635	0.22075	0.27442	0.33265
0	30.0	0.05519	0.11099	0.16635	0.22068	0.27437	0.33258
0	22.5	0.05518	0.11083	0.16630	0.22065	0.27421	0.33239
0	15.0	0.05518	0.11104	0.16630	0.22054	0.27412	0.33224
0	7.5	0.05517	0.11101	0.16625	0.22048	0.27422	0.33223
90	37.5	0.05540	0.11107	0.16624	0.22041	0.27341	0.33221
90	30.0	0.05523	0.11113	0.16625	0.22043	0.27338	0.33208
90	22.5	0.05522	0.11114	0.16623	0.22040	0.27343	0.33214
90	15.0	0.05522	0.11106	0.16624	0.22038	0.27337	0.33201
90	7.5	0.05521	0.11112	0.16623	0.22040	0.27335	0.33196

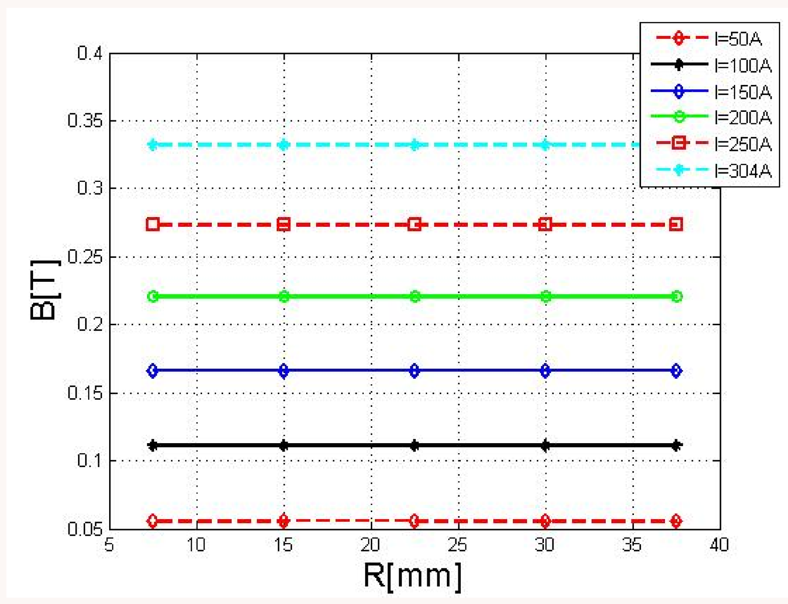

Fig. 6: Experimental data of B[T] vs. radius ,$z = 0$mm

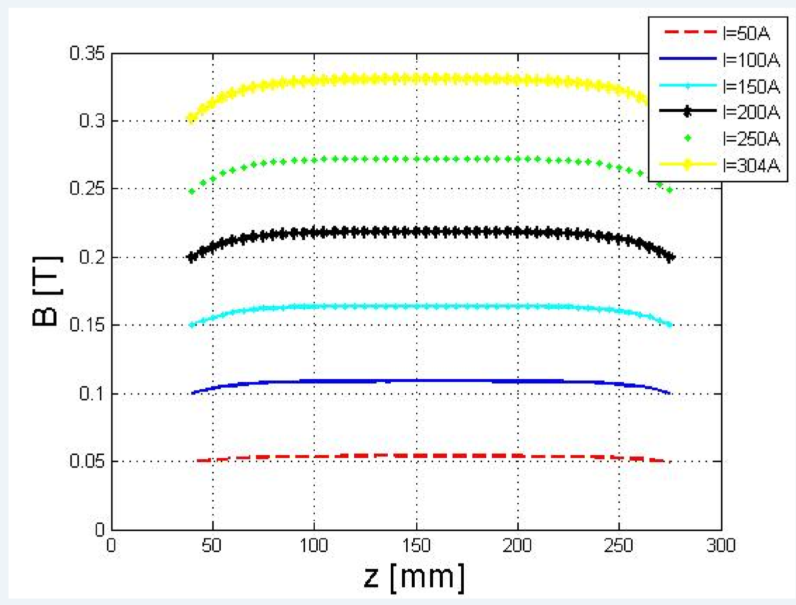

Fig. 8: Experimental Data vs. z-axis, $R_0 = 0$mm

Relative standard deviation

$$\varepsilon = |B_m - B_c|/B_c \cdot 100\% = 1.85117\%. \quad (5)$$

$\varepsilon = \varepsilon_{max}$ at $\theta^0 = 90^0$ and $I_2 = 100$A.

Polynomial approximation

$$f(I_k) = 10.91 \cdot 10^{-4} I_k - 9.687 \cdot 10^{-5} \quad (6)$$

where $f = B_0 = B(0, 0, 0)$

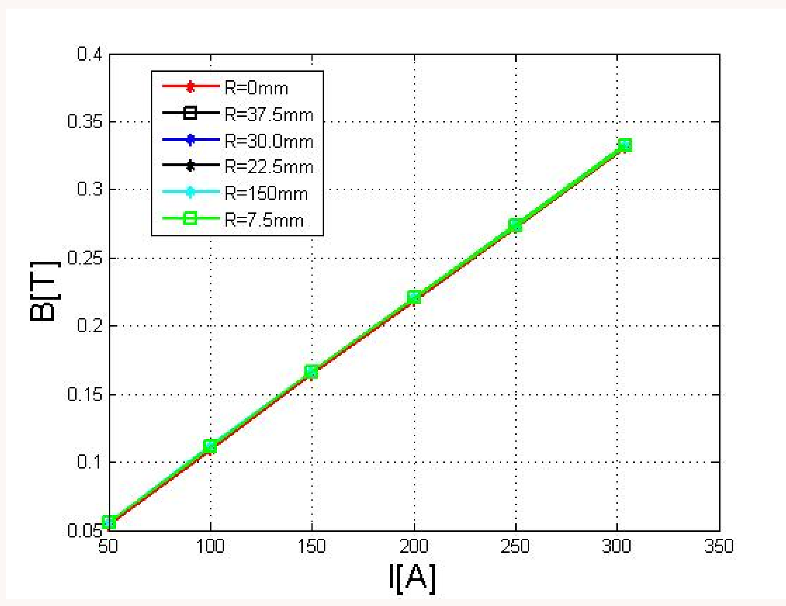

Fig. 7: B_0 vs. I, $z = 0$

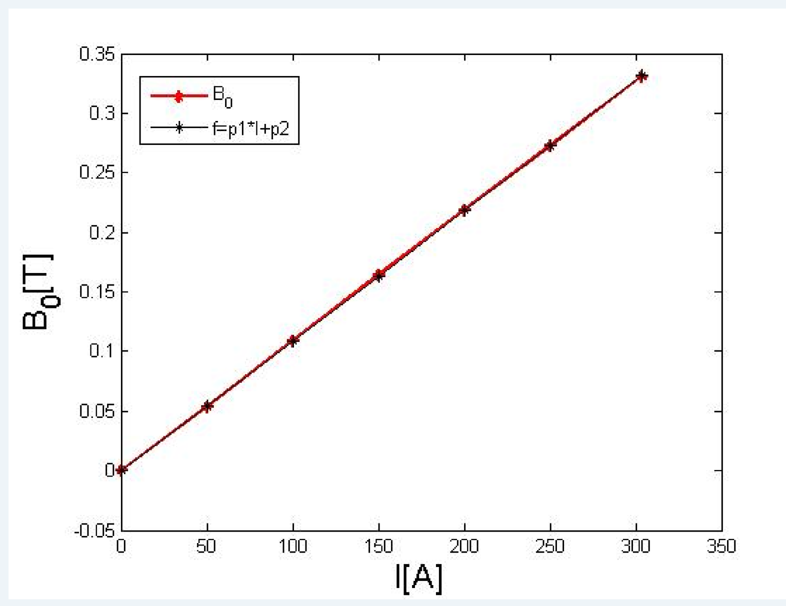

Fig. 9: Polynomial approximation vs. measured values

Conclusions

- The greatest error of experimental data towards the calculated data is less than 2%. So we conclude that the data of experiment, were achieved with acceptable accuracy.
- The analysis of experimental data it follows that the error decreases to increase the current, but increases with the distance to the center of the electromagnet.
- Polynomial approximation (6) is the best approximation of the field in the center of the magnet and may be useful in calculating the magnetic field for any current.
- Figure 8 shows the variation of magnetic flux density along the axis Oz and we can see the end effects.